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Indoor Wood-Burning Stove and Fireplace Use and Breast Cancer in a Prospective Cohort Study

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Background: Indoor burning of fuel for heating or cooking releases carcinogens. Little is known about the impact of indoor air pollution from wood-burning stoves or fireplaces on breast cancer risk.

Objectives: In a large prospective cohort study, we evaluated the risk of breast cancer in relation to indoor heating and cooking practices.

Methods: Sister Study participants ($n = 50{,}884$) were recruited from 2003–2009. Breast cancer–free women in the United States or Puerto Rico, 35–74 y old, with a sister with breast cancer were eligible. Participants completed questionnaires on indoor heating and cooking practices for both their enrollment and their longest adult residence. Cox regression was used to estimate adjusted hazard ratios (HRs) and 95% confidence intervals (95% CIs) for the association between indoor heating/cooking and breast cancer.

Results: A total of 2,416 breast cancer cases were diagnosed during follow-up (mean = 6.4 y). Having an indoor wood-burning stove/fireplace in the longest adult residence was associated with a higher breast cancer risk [HR = 1.11 (95% CI: 1.01, 1.22)]; the risk increased with average frequency of use [≥once/week, HR = 1.17 (95% CI: 1.02, 1.34)] (p for trend = 0.01). An elevated HR was seen for women burning wood [HR = 1.09 (95% CI: 0.98, 1.21)] or natural gas/propane [HR = 1.15 (95% CI: 1.00, 1.32)]. No association was observed for burning artificial fire-logs [HR = 0.98 (95% CI: 0.85, 1.12)] except among women from western states [HR = 1.36 (95% CI: 1.02, 1.81)].

Conclusions: In this prospective study, using an indoor wood-burning stove/fireplace in the longest adult residence at least once a week and burning either wood or natural gas/propane was associated with a modestly higher risk of breast cancer. https://doi.org/10.1289/EHP827

Introduction

Indoor air pollution, also referred to as household air pollution, is a public health issue of concern throughout the world. It was estimated that approximately 2.8 billion people across the globe were exposed to indoor air pollution from burning biomass indoors in 2010 (Bonjour et al. 2013). The International Agency for Research on Cancer (IARC) has classified indoor air pollution from the combustion of biomass as a Group 2A, or probable, carcinogen (IARC 2010b). The majority of the previous research on the carcinogenic potential of indoor air pollution has focused on cancers of the lung (Hosgood et al. 2010; Lissowska et al. 2005; Sapkota et al. 2008) or aerodigestive tract (Sapkota et al. 2008). Understanding the impact of indoor air pollution on other types of cancer, such as breast cancer, has recently been highlighted as a research priority (Reid et al. 2012).

Burning biomass, such as wood, in the home can result in exposure to carcinogens that are similar to those found in tobacco smoke (IARC 2010b); for example, wood burning in the home is highly correlated with levels of polycyclic aromatic hydrocarbons (PAHs), benzene, and 1,3-butadiene, as well as other compounds (Gustafson et al. 2007; Gustafson et al. 2008). Wood burning in an open fireplace produces PAHs at levels that are comparable to those in ambient urban air (Alfheim and Ramdahl 1984). Only one prior report, a retrospective case–control study, evaluated indoor wood-burning stove/fireplace use as a breast cancer risk factor (White et al. 2014). The study observed a positive association with breast cancer for women who reported burning artificial or synthetic fire-logs (White et al. 2014).

In this large prospective cohort study, we considered measures of residential indoor heating and cooking in association with breast cancer risk. We hypothesized that using an indoor wood-burning stove/fireplace would be associated with a higher breast cancer risk and that the risk may vary with material burned and frequency of use. Indoor wood-burning stove/fireplace use is a potentially modifiable breast cancer risk factor, and better understanding of the role played by indoor air pollution in breast carcinogenesis may inform public health strategies to reduce breast cancer risk.

Methods

Study Population

The Sister Study is a prospective volunteer-based cohort study that was designed to evaluate environmental risk factors for breast cancer. Women were recruited for the study from 2003–2009 using a multimedia campaign and a network of breast cancer professionals and advocates. Eligibility criteria included having no personal history of breast cancer, living in the United States or Puerto Rico, being between 35–74 y of age, and having a sister who had been previously diagnosed with breast cancer. At baseline, Sister Study participants completed an extensive telephone questionnaire covering demographics, lifestyle factors, medical and family history, and residential history, including questions on indoor heating and cooking at both baseline and their longest adult residence.

This research was approved by the Institutional Review Boards of the National Institute of Environmental Health Sciences (NIEHS), the National Institutes of Health (NIH), and the Copernicus Group. Written informed consent was obtained from all participants. This study includes breast cancer cases that were diagnosed before July 1, 2014 (Sister Study Data Release 4.1).

Outcome Assessment

Study participants complete annual health updates to notify the study about any changes in health as well as additional

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comprehensive questionnaires every 2–3 y. Participation rates have been >90% throughout the follow-up period (NIEHS 2016).

Medical records are used to confirm the breast cancer diagnosis and have been successfully obtained for ~80% of cases. The agreement between self-reported tumor characteristics and information abstracted from the medical record is high, and therefore, self-reported data are used when medical record data are not available (D'Aloisio et al., unpublished data, 2016).

Exposure and Covariate Assessment

As part of the residential history questionnaire given at baseline, study participants were asked for details on their indoor heating and cooking sources for both their baseline residence and their longest adult residence (since the age of 20). For both the baseline and the longest adult residence, information on the age starting and stopping living in the home was collected. Women were asked whether there was an indoor wood-burning stove or a fireplace in their home (yes, no) and the frequency of use (average number of times per year). Frequency of indoor stove/fireplace use was collapsed to less than once per month, 1–4 times per month, and at least once per week. Women who reported having an indoor wood-burning stove/fireplace in their residence but estimated zero uses per year (11%) were excluded from the frequency-of-use analysis. The questionnaire also asked about the type of material burned in the indoor stove/fireplace (wood, coal, natural gas or propane, or artificial logs). For material burned, participants could select multiple fuel types. Study participants also answered questions on the main source of heating in the home (electricity, natural gas, fuel oil, propane, wood, or other) and the energy source for the cooking stove top or top range (electricity, gas or natural gas, or other). See Supplemental Material, "Sister Study Baseline Residential Questionnaire," for specific wording of the questions.

Covariates of potential interest, including demographics, reproductive history, cigarette smoking, and use of exogenous hormones, were obtained from the baseline interview. A trained examiner measured height and weight at the baseline home visit; measurements were used to determine body mass index (BMI; kilograms/square meter).

Statistical Analysis

To evaluate the association between indoor heating and cooking and breast cancer risk, multivariable Cox proportional hazards models were used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs). Follow-up was accrued from age at baseline to age at breast cancer diagnosis or censoring (defined as the age of last follow-up).

Overall breast cancer ($n=2{,}416$), invasive breast cancer ($n=1{,}843$), and ductal carcinoma *in situ* (DCIS) ($n=533$) were considered as outcomes of interest. We also evaluated the association between breast cancer and indoor wood-burning stove and fireplace use when breast cancer was defined using estrogen receptor status (ER+,ER-) and menopausal status at diagnosis (premenopausal, postmenopausal) as secondary outcomes. When evaluating by ER subtype or invasive/DCIS status, cases without the breast cancer subtype of interest were censored at the time of diagnosis. ER analyses were restricted to women with invasive breast cancer because ER status is less frequently reported for *in situ* disease. A case–case analysis was used to test whether effect estimates differed by subtype or invasive/DCIS status (Begg and Zhang 1994). When evaluating breast cancer risk by menopausal status at diagnosis, women who became postmenopausal during the follow-up period were censored for premenopausal breast cancer at age of menopause and then became at risk for postmenopausal breast cancer. The assumption of proportional hazards for the Cox model was evaluated visually using log–log survival plots and via an interaction term in the model between each covariate and survival time (using an $\alpha=0.05$). There was no evidence of time-variant associations.

Effect measure modification of the relationship between breast cancer and indoor wood-burning stove/fireplace use by geographic region (northeast, west, south, midwest), smoking status (never smoker, ever smoker), education (≤high school graduate, some college, 4-y college degree, graduate degree), and number of first-degree relatives with breast cancer was tested. Confounders were identified using a directed acyclic graph (Greenland et al. 1999). Multivariable-adjusted models included race (non-Hispanic white, other), education (<high school degree, completed high school or General Education diploma (GED), some college but no degree, associate's or technical degree, bachelor's degree, Master's degree, doctoral degree), marital status (never married, legally married or living as married, widowed or divorced or separated), annual household income (<20,000 USD, 20,000–49,999 USD, 50,000–99,999 USD, 100,000–199,999 USD, ≥200,000 USD), parity (nulliparous, parous), use of oral contraceptives (ever, never), hormone replacement therapy use at enrollment (none, estrogen only, estrogen and progesterone combined or both estrogen and estrogen and progesterone combined), age at menopause (premenopausal, <40 y, 40–50 y, 51–55 y, >55 y based on enrollment information), and BMI (<18.5 kg/m^2, 18.5–24.9 kg/m^2, 25.0–29.9 kg/m^2, ≥30 kg/m^2). All confounders were modeled as categorical variables using the characterizations described above.

For sensitivity analyses, we restricted to women whose longest adult residence was also their baseline residence. Two-sided tests were used with a p-value of 0.05 to evaluate statistical significance. All analyses were performed using SAS software (version 9.3; SAS Institute Inc.).

Results

Having an indoor wood-burning stove or fireplace was common in our study population, with over half of the participants reporting having one at their longest adult residence. Women in the Sister Study who had a wood-burning stove/fireplace in their home were more likely to be non-Hispanic white, to have higher educational attainment, and to have higher annual household income (Table 1). Indoor wood-burning stove/fireplace users were also more likely to use oral contraceptives and postmenopausal hormones.

There were 2,416 breast cancers diagnosed during the follow-up period (mean = 6.4 y), 1,843 of which were determined to be invasive. Having a wood-burning stove/fireplace in the longest adult residence was associated with slightly increased breast cancer risk [Number of exposed cases (n) = 1,500; HR = 1.11 (95% CI: 1.01, 1.22)] (Table 2). There was a trend of higher breast cancer risk with increased frequency of use ($p=0.01$); those who used an indoor wood-burning stove/fireplace at least once a week had the highest HR [$n=327$; HR = 1.17 (95% CI: 1.02, 1.34)] relative to those who did not have a wood-burning stove/fireplace in their longest adult residence. Although the HR for invasive cases did not differ significantly from *in situ* cases in a direct comparison, the estimate for weekly wood-burning stove/fireplace use was apparent for invasive breast cancer [$n=265$; HR = 1.25 (95% CI: 1.07, 1.46)] but not for DCIS [$n=59$; HR = 0.96 (95% CI: 0.70, 1.31)] (invasive vs. DCIS, $p=0.7$).

An increased risk of breast cancer was observed for women who burned wood ($n=924$ HR = 1.09 (95% CI: 0.98, 1.21)] or natural gas/propane [$n=353$ HR = 1.15 (95% CI 1.00, 1.32)] in their wood-burning stove/fireplace compared with those without

Table 1. Study population characteristics at baseline by presence of an indoor wood-burning stove/fireplace at longest adult residence, National Institute of Environmental Health Sciences (NIEHS) Sister Study.

Characteristic	No indoor wood-burning stove/fireplace $n = 18,017$	Indoor wood-burning stove/fireplace $n = 29,495$
Continuous, mean (standard deviation)		
Age at baseline	54.6 (9.2)	55.7 (8.7)
Age at menopause[a]	47.5 (6.7)	48.6 (6.2)
Body mass index (kg/m^2)	28.8 (6.8)	27.2 (5.9)
Categorical, *n* (%)		
Parity		
Parous	14,220 (79.0)	24,567 (83.3)
Smoking status		
Ever	8,244 (45.8)	12,551 (42.6)
Race		
Non-Hispanic white	13,543 (75.2)	26,274 (89.1)
Education		
Less than high school degree	412 (2.3)	167 (0.6)
High school degree or equivalent	3,136 (17.4)	3,440 (11.7)
Some college, no degree	3,949 (21.9)	5,308 (18.0)
Associate's degree	2,827 (15.7)	3,903 (13.2)
4-y degree	4,248 (23.6)	8,667 (29.4)
Master's degree	2,884 (16.0)	6,592 (22.4)
Doctoral degree	558 (3.1)	1,414 (4.8)
Marital status		
Never married	1,611 (8.9)	972 (3.3)
Legally married or living as married	11,800 (65.5)	23,765 (80.6)
Separated, divorced or widowed	4,603 (25.6)	4,752 (16.1)
Annual household income		
<20,000 USD	1,443 (8.3)	666 (2.4)
20,000–49,999 USD	5,060 (29.0)	4,372 (15.5)
50,000–99,999 USD	7,299 (41.8)	11,343 (40.2)
100,000–199,999 USD	3,112 (17.8)	9,031 (32.0)
≥200,000 USD	535 (3.1)	2,833 (10.0)
Geographic location		
Northeast	3,605 (21.3)	5,242 (17.8)
Midwest	5,470 (32.4)	7,864 (26.7)
South	5,260 (31.1)	8,874 (30.2)
West	2,572 (15.2)	7,427 (25.3)
Use of oral contraceptives		
Ever	14,726 (81.8)	25,342 (86.0)
Postmenopausal hormone use[a]		
None	4,636 (42.9)	6,897 (36.4)
Estrogen only (E)	3,083 (28.5)	5,285 (27.9)
Estrogen and Progesterone (E + P) or E and E + P	3,093 (28.6)	6,747 (35.6)

Note: Chi-squared *p*-value for all study characteristics $p < 0.0001$. USD, U.S. dollar.
[a]Limited to those who were postmenopausal at baseline ($n = 32,457$).

a wood-burning stove/fireplace in their home. There was no evidence of an increase in risk for burning artificial fire-logs [$n = 339$; HR = 0.98 (95% CI: 0.85, 1.12)]. Although there was not a significant interaction for any wood-burning stove/fireplace by geographic region (p for interaction = 0.1), there was some suggestion of variability in the association of any wood-burning stove/fireplace use and breast cancer risk by geographic region (see Table S1). For example, the association with having an indoor wood-burning stove/fireplace was most pronounced in women residing in western states [$n = 404$; HR = 1.32 (95% CI: 1.05, 1.66)], and this elevated association was observed for all materials burned including artificial fire logs [wood, $n = 247$; HR = 1.30 (95% CI: 1.02, 1.67); gas, $n = 91$; HR = 1.30 (95% CI: 0.96, 1.76); artificial logs, $n = 111$; HR = 1.36 (95% CI: 1.02, 1.81)]. Frequency of fireplace use was highest in women living in the west (mean = 40 times/y) or northeast (mean = 41 times/y) compared with those living in the south (mean = 24.9 times/y) or midwest (mean = 34.7 times/y).

There were slight increases in breast cancer risk observed for gas [$n = 1,302$; HR = 1.09 (95% CI: 0.98, 1.21)] or fuel oil [$n = 249$; HR = 1.13 (95% CI: 0.97, 1.32)] as the main heating sources in the home compared with electricity (Table 2). Although few women reported wood as the primary heating source of the home, there was suggestive evidence of elevated invasive breast cancer risk for wood heating relative to electricity use [$n = 47$; HR = 1.27 (95% CI: 0.93, 1.73)]. Estimates were similar when restricting to women whose longest residence was also their baseline residence (see Table S2). Estimates were attenuated toward the null when we considered indoor wood-burning stove/fireplace and heating/cooking exposure information from the baseline residence compared with estimates for exposure at the longest adult residence (see Table S3).

There was little evidence that the association between indoor wood-burning stove/fireplace use and breast cancer differed with increasing years lived in the longest residence [<10 y, $n = 255$; HR = 1.09 (95% CI: 0.89, 1.35); ≥10 y, $n = 1,245$; HR = 1.12 (95% CI: 1.00, 1.24)] (Table 3), although the estimate was statistically significant only among those who reported living ≥10 y in the longest adult residence. Having an indoor wood-burning stove/fireplace in the longest adult residence was associated with both invasive ER+ [$n = 891$; HR = 1.16 (95%CI 1.02, 1.31)] and invasive ER– [$n = 165$; HR = 1.30 (95% CI 0.96, 1.74)] tumor status (Table 4). The HRs did not vary by menopausal status at diagnosis.

There was no evidence to suggest that the association between indoor wood-burning stove/fireplace use varied by number of first-degree relatives with breast cancer (see Table S4) or by smoking history (see Table S5). Similarly, there was no evidence of a significant interaction by education (see Table S6).

Discussion

In this large, prospective cohort of women with a family history of breast cancer, those who used an indoor wood-burning stove or fireplace at their longest adult residence were at a higher risk of developing breast cancer. The risk of breast cancer increased with more frequent use, and the association varied based on the material burned, with both wood and natural gas/propane being associated with an elevated risk. There were also modest associations observed for reporting that gas, fuel oil, or wood was the main source of heating at the longest adult residence relative to electricity. This is the first prospective study to consider measures of indoor heating/cooking in association with breast cancer risk.

The association between indoor air pollution and breast cancer is biologically plausible. Use of an open fireplace has been associated with higher DNA adduct levels (Pedersen et al. 2009), which have been related to breast carcinogenesis (Gammon et al. 2004). Although gas fireplaces are thought to produce less air pollution (U.S. EPA 2016), gas fireplaces produce PAHs, nitrogen dioxide, and carbon monoxide (Dutton et al. 2001). Burning wood releases numerous compounds, including PAHs, 1,3-butadiene, polychlorinated dibenzodioxins and dibenzofurans (PCDDs/Fs), polychlorinated biphenyls (PCBs), hexachlorobenze (HxCBz), and particulate matter, among others (Gullett et al. 2003; Gustafson et al. 2007; McDonald et al. 2000; Rogge et al. 1998). Once PAHs are inhaled, they can be rapidly absorbed and can eventually accumulate in the breast (IARC 2010a). PAHs are established carcinogens and can bind to DNA to form bulky adducts in the breast tissue that, if not sufficiently repaired, can lead to somatic mutations (IARC 2010a). Another potentially relevant biologic mechanism is that of epigenetic modification. PAH exposure sources have been associated with aberrant DNA methylation of breast cancer–related genes, which

Table 2. Indoor heating/cooking at longest adult residence and breast cancer, National Institute of Environmental Health Sciences (NIEHS) Sister Study.

Indoor air pollution at longest adult residence	Person-years ($n = 362,242$)	All breast cancer ($n = 2,416$)	Invasive breast cancer ($n = 1,843$)	DCIS ($n = 533$)	Age-adjusted Overall HR (95% CI)	Multivariable-adjusted[a] Overall HR (95% CI)	Multivariable-adjusted[a] Invasive HR (95% CI)	Multivariable-adjusted[a] DCIS HR (95% CI)
Indoor wood-burning stove/fireplace								
No stove/fireplace	113,647	754	567	170	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Yes	192,317	1500	1151	329	1.15 (1.05, 1.25)*	1.11 (1.01, 1.22)*	1.13 (1.02, 1.26)*	1.07 (0.87, 1.31)
Indoor wood-burning stove/fireplace frequency of use								
No stove/fireplace	113,647	754	567	170	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Less than once/month	59,782	449	340	102	1.11 (0.99, 1.25)	1.06 (0.93, 1.20)	1.07 (0.93, 1.24)	1.01 (0.77, 1.32)
1–4 times/mo	53,920	418	307	103	1.15 (1.02, 1.30)*	1.13 (0.99, 1.28)	1.11 (0.95, 1.28)	1.22 (0.94, 1.58)
at least once a week	40,856	327	265	59	1.18 (1.03, 1.34)*	1.17 (1.02, 1.34)*	1.25 (1.07, 1.46)*	0.96 (0.70, 1.31)
Indoor wood-burning stove/fireplace fuel[b]								
No stove/fireplace	113,647	754	567	170	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Wood	120,549	924	718	190	1.12 (1.02, 1.24)*	1.09 (0.98, 1.21)	1.13 (1.00, 1.27)	0.97 (0.77, 1.21)
Gas	45,578	353	271	79	1.16 (1.03, 1.32)*	1.15 (1.00, 1.32)*	1.19 (1.02, 1.39)*	1.07 (0.81, 1.43)
Artificial logs	49,737	339	245	87	1.02 (0.90, 1.16)	0.98 (0.85, 1.12)	0.94 (0.80, 1.10)	1.08 (0.82, 1.42)
Energy source for the cooking stove top								
Electricity	185,435	1397	1061	316	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Gas	107,850	794	605	174	1.00 (0.91, 1.09)	0.99 (0.90, 1.08)	1.00 (0.90, 1.10)	0.94 (0.78, 1.14)
Other	32,956	225	177	43	0.86 (0.74, 0.99)*	0.86 (0.75, 1.00)*	0.90 (0.76, 1.06)	0.73 (0.52, 1.02)
Main source of heating								
Electricity	75,395	523	395	121	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Gas	170,459	1302	987	295	1.07 (0.97, 1.19)	1.09 (0.98, 1.21)	1.09 (0.97, 1.23)	1.07 (0.86, 1.33)
Fuel oil	30,457	249	193	50	1.11 (0.96, 1.29)	1.13 (0.97, 1.32)	1.14 (0.95, 1.37)	1.04 (0.74, 1.46)
Propane	12,293	66	53	12	0.75 (0.58, 0.97)*	0.83 (0.64, 1.07)	0.89 (0.66, 1.18)	0.62 (0.33, 1.15)
Wood	7,457	54	47	6	1.03 (0.78, 1.36)	1.09 (0.82, 1.45)	1.27 (0.93, 1.72)	0.55 (0.24, 1.26)
Other	5,952	37	26	9	0.90 (0.64, 1.25)	0.90 (0.63, 1.27)	0.87 (0.58, 1.31)	0.90 (0.44, 1.85)

Note: CI, confidence interval; DCIS, ductal carcinoma *in situ*; HR, hazard ratio

[a]Adjusted for age, race, education, income, marital status, parity, use of hormonal birth control, use of postmenopausal hormones, age at menopause and menopausal status, and body mass index (BMI).

[b]Fuel types are not mutually exclusive.

*$p < 0.05$.

can result in altered expression patterns that promote carcinogenesis (White et al. 2016).

The pollutants released from indoor heating and cooking methods are estimated to be at a concentration higher than that of environmental tobacco smoke but lower than active smoking (Smith and Peel 2010). Previous studies have reported modest, but positive, associations between breast cancer and both active smoking and environmental tobacco smoke (DHHS 2014). Similarly, the growing body of literature on the association between outdoor air pollution measures and breast cancer supports the findings observed in this study. Most studies have reported an increased risk of breast cancer in association with markers of higher traffic-related air pollution, including nitrogen dioxide and PAHs (Crouse et al. 2010; Mordukhovich et al. 2016; Reding et al. 2015). Two studies of early-life exposure to total suspended particles, a proxy for PAH exposure, also reported positive associations with later breast cancer risk (Bonner et al. 2005; Nie et al. 2007). Outdoor air pollution is a source of indoor air pollution and thus could potentially interact with indoor air pollution from indoor wood-burning stoves/fireplaces to influence breast cancer risk. Thus, any geographic variability in the constituents of outdoor air pollution could potentially have contributed to any geographic differences in the estimates reported in this study.

The findings reported here conflict somewhat with those of the Long Island Breast Cancer Study Project (LIBCSP), a

Table 3. Indoor wood-burning stove/fireplace at longest adult residence and overall breast cancer risk by years lived at residence, National Institute of Environmental Health Sciences (NIEHS) Sister Study.

	Residence duration			
	<10 y		≥10 y	
Indoor wood-burning stove/fireplace in longest adult residence	n	HR (95% CI)[a]	n	HR (95% CI)[a]
Indoor wood-burning stove/fireplace				
No stove/fireplace	164	1.00 (Referent)	589	1.00 (Referent)
Yes	255	1.09 (0.89, 1.35)	1,245	1.12 (1.00, 1.24)*
Indoor wood-burning stove/fireplace fuel				
No indoor stove/fireplace	164	1.00 (Referent)	589	1.00 (Referent)
Wood	154	1.13 (0.89, 1.42)	770	1.08 (0.96, 1.22)
Gas	79	1.16 (0.86, 1.55)	274	1.15 (0.98, 1.34)
Artificial logs	62	0.86 (0.63, 1.17)	277	1.01 (0.86, 1.17)

Note: CI, confidence interval; HR, hazard ratio.

[a]Adjusted for age, race, education, income, marital status, parity, use of hormonal birth control, use of postmenopausal hormones, age at menopause and menopausal status, and body mass index (BMI).

*$p < 0.05$.

Table 4. Indoor wood-burning stove/fireplace at longest adult residence and breast cancer tumor characteristics, National Institute of Environmental Health Sciences (NIEHS) Sister Study.

	No indoor wood-burning stove/fireplace		Indoor wood-burning stove/fireplace	
Tumor characteristics	*n*	HR (95% CI)[a]	*n*	HR (95% CI)[a]
Estrogen receptor (ER) status[b]				
ER +	416	1.00 (Referent)	891	1.16 (1.02, 1.31)*
ER −	75	1.00 (Referent)	165	1.30 (0.96, 1.74)
Menopausal status at diagnosis				
Premenopausal	180	1.00 (Referent)	315	1.09 (0.90, 1.33)
Postmenopausal	569	1.00 (Referent)	1,180	1.10 (0.99, 1.23)

Note: CI, confidence interval; HR, hazard ratio.
[a]Estrogen receptor analyses and postmenopausal models adjusted for age, race, education, income, marital status, parity, use of hormonal birth control, use of postmenopausal hormones, age at menopause and menopausal status, and body mass index (BMI). Premenopausal models adjusted for age, race, education, income, marital status, parity, use of hormonal birth control, use of postmenopausal hormones, and BMI.
[b]Estrogen receptor status analyses limited to invasive cases.
*$p < 0.05$.

retrospective case–control study of women on Long Island, New York ($n = 1{,}508$ cases and $n = 1{,}556$ controls). In the LIBCSP, there was an increase in odds of breast cancer observed in women who reported burning synthetic logs, whereas no increase in risk was observed for women who reported burning wood or gas (White et al. 2014). The discrepancies between these two studies may be due to a number of factors. First, women in the LIBCSP were geographically constrained to Long Island, NY based on enrollment criteria, whereas women in the Sister Study population could have lived anywhere in the United States or Puerto Rico. To address this specific difference in these study populations, we conducted an analysis stratifying by geographic region. When restricted to Sister Study participants living in the northeast, burning wood or gas in wood-burning stoves/fireplaces was not associated with breast cancer risk, similar to the LIBCSP findings. However, we did not see a similar association with use of artificial fire-logs in this subgroup.

The women in the LIBCSP were diagnosed between 1996 and 1997 (Gammon et al. 2002), whereas the women in our study population were diagnosed after their enrollment in the study between 2003 and 2009. Changes in fireplace construction and/or indoor ventilation may have led to variation in indoor air emissions from indoor wood-burning stoves/fireplaces over time (Houck et al. 1998), and construction may vary geographically along with frequency of wood-burning stove/fireplace use. The composition of synthetic fire-logs has also changed over time (Li and Rosenthal 2006), which may partially explain some of the differences in the findings. Finally, the LIBCSP study did not consider frequency of indoor wood-burning stove/fireplace use and thus was not able to identify those with higher levels of exposure and could not rule out the potential for recall bias.

In addition to observing an increase in risk for burning wood or natural gas in an indoor wood-burning stove/fireplace, we found similar associations for wood, gas, and fuel oil as the main heating sources relative to electricity. The association observed with wood as fuel for the stove/fireplace and as the main heating source was only evident for invasive tumors. Invasive breast cancer and *in situ* disease may have distinct etiologies and thus different risk factors (Kerlikowske et al. 1997).

We saw little evidence that associations with wood-burning stove/fireplace use were stronger with increasing years lived at the longest adult residence. However, we did observe that associations were attenuated for indoor heating/cooking measures at the baseline residence compared with the longest adult residence. This finding suggests that there is some importance of increasing duration of exposure to indoor air pollution with respect to breast cancer. There was an inverse association observed with other energy sources for a cooking-stove top; it is unclear why this would be the case, but estimates were imprecise.

Although the test of effect measure modification was not statistically significant, there was some evidence of variability in the association between wood-burning stove/fireplace use and breast cancer by geographic region. In particular, estimates were most notable in women who were living in the western United States. It is unclear why this would be the case; the frequency of wood-burning stove/fireplace use in women who lived in western states was similar to the frequency of use in women who lived in the northeast, where no increase in risk was observed. A limitation of this study is that we did not capture differences in frequency of use by seasons, which is highly likely to vary by geographic region. A report from the U.S. EPA suggested that fireplaces in the west were notably larger and thus would produce more emissions (Houck et al. 1998), which may explain, possibly in conjunction with differences in age of home and ventilation, the increase in risk observed for women in the west, if this effect is real.

The information on indoor heating and cooking is self-reported. Our questionnaire was limited to the participant's residence at study baseline as well as their longest adult residence, which may have helped to maximize recall. Any recall error would not have been differential by case status because information on fireplace use was collected before breast cancer diagnosis. However, because we did not collect information on residences other than longest adult and baseline residence, we were unable to consider exposure information for some women who may have used wood-burning indoor stoves/fireplaces at other residences, and we did not capture information on ventilation or other factors that may affect level of exposure from fireplaces and indoor wood-burning stoves. In our study, although the HR for invasive cancer was greater for those who used fireplaces at least once a week, we did not have the sample size to distinguish very heavy users (e.g., those who used them every day) from more occasional users.

The prospective design of this study is an important strength. Additionally, the inclusion of both frequency of use and material burned are strengths of this analysis. However, the questionnaire combined indoor wood-burning stoves and fireplaces into a single question; thus, we were unable to differentiate between the two. This is a limitation because sealed indoor stoves may release reduced emissions compared with open fireplaces (Gullett et al. 2003; McDonald et al. 2000), and use of wood-burning stoves versus fireplaces may vary geographically as well as by other participant characteristics such as socioeconomic status. Indoor wood-burning stove/fireplace use was more common in women who had a higher income or educational attainment. Higher socioeconomic status is an established risk factor for breast cancer (Yost et al. 2001). Although we were able to adjust for detailed education and income information, as well as for marital status, we cannot rule out the possibility that there was some residual confounding by socioeconomic status that we were unable to resolve.

The women in this study population have a family history of breast cancer. To evaluate whether family history modified the association between wood-burning stove/fireplace use and breast cancer, we considered degree of family history as an effect measure modifier. There was no evidence that the association varied based on the number of first-degree family members with breast cancer. Although we cannot be sure that these results are

generalizable to all women, we do expect women in this study population to have similar risk factor distributions to the general population (Weinberg et al. 2007).

Conclusions

In conclusion, this is the first prospective study to examine the association between indoor stove/fireplace use and breast cancer risk. We found that using an indoor wood-burning stove/fireplace was associated with a higher risk of breast cancer in a study population of women with a family history of breast cancer. The association with indoor wood-burning stove/fireplace use increased with both frequency and years of use. Indoor air pollution is of worldwide concern, particularly in areas where burning of wood and other materials for both heating and cooking is common; in our study population, over half of the women reported using an indoor wood-burning stove or fireplace. Despite the modest 10–15% increase in risk observed in this study, the high prevalence of indoor wood-burning stove and fireplace use as well as the continued high incidence of breast cancer suggest that these findings could have substantial public health impact. Indoor air pollution from indoor wood-burning stoves/fireplaces is a widespread and potentially modifiable breast cancer risk factor.

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